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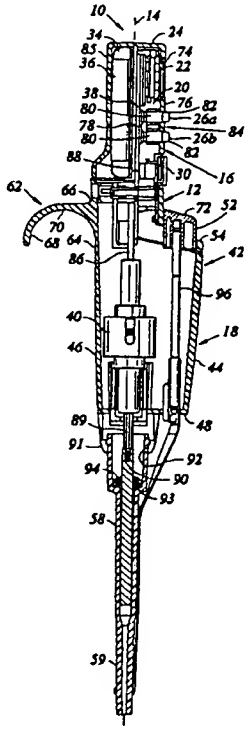
(54) Title: IMPROVED BATTERY POWERED MICROPROCESSOR CONTROLLED HAND PORTABLE ELECTRONIC PIPETTE

(57) Abstract

A battery powered, microprocessor controlled portable electronic pipette (10), comprising a hand holdable housing supporting a battery (16), a linear actuator (40) for driving a plungner (90) lengthwise in a cylinder to aspirate and dispense fluid into and from a pipette tip (60) extending from the housing and a control circuit for the linear actuator. The linear actuator is powered by the battery and comprises a stepper motor (40) with current receiving windings for electromagnetically driving a rotor to impart the lengthwise movement to the plunger (90).



IMPROVED BATTERY POWERED MICROPROCESSOR CONTROLLED HAND PORTABLE ELECTRONIC PIPETTE

Related Application

This is a continuation-in-part of United States patent application filed March 5, 1999, Serial No. 09/263,132.

Field of Invention

The present invention relates to pipettes and more particularly to a battery powered microprocessor controlled hand portable electronic pipette which is light in weight and easily operated by a user over extended periods of time.

Background

Since the first commercial introduction of a battery powered microprocessor controlled hand-holdable and easily transportable electronic pipettes by the Rainin Instrument Co., Inc., assignee of the present invention, it has been and continues to be the desire of all electronic pipette manufacturers to provide electronic pipettes which have the functional feel and operational capabilities of manual pipettes such as the world famous PIPETMAN pipette sold exclusively in the United States by the Rainin Instrument Co. for more than 25 years. Specifically in this regard, it continues to be the goal of all electronic pipette manufacturers to develop and produce electronic pipettes that

manufacturers to develop and produce electronic pipettes that are light in weight, easily holdable and transportable by a user and operational in several modes of operation over extended periods of time without creating physical stress and strain of the hands and forearms of the pipette user. The EDP electronic pipette of the Rainin Instrument Co. introduced in 1984 and its successor models addressed each of the foregoing design criteria. Following Rainin, other companies developing and manufacturing electronic pipettes have also addressed the same criteria and over the years electronic pipettes have become somewhat lighter in weight and more user friendly. However, the desire for an electronic pipette which closely approximates in feel and operational features those of the manual pipette have never been completely achieved. Accordingly, there continues to be a need for such an electronic pipette which is satisfied by the present invention.

Summary of Invention

Basically, the present invention satisfies the foregoing needs by providing an electronic pipette which is light in weight, comfortably holdable in either the right or left hand of a user and which is easily operated by the user to direct microprocessor controlled operation of the pipette through different user selected modes of operation for different user selected sample volume and speeds of operation. In providing

different user selected modes of operation for different user selected sample volume and speeds of operation. In providing such a user friendly electronic pipette, the present invention comprises a bilaterally symmetrical design described in detail in the concurrently filed United States patent application serial no. 09/263,131, which is incorporated herein by this reference. Basically, the design includes an axially elongated hollow housing having a vertically extending longitudinal axis and vertically extending and substantially coaxial upper and lower portions. The upper portion of the housing includes a forward compartment containing a forwardly facing alpha-numeric display adjacent a top of the housing. Thus located, the display is readily viewable by a user during all modes of operation of the pipette be the user right handed or left handed. In addition to the display, the forward compartment contains a plurality of columns of forwardly facing control keys as well as a plurality of forwardly facing trigger switches below the columns of control keys. The display, columns of control keys and trigger switches are bilaterally symmetrical relative to the longitudinal axis of the housing. In addition, the upper portion of the housing includes a rear compartment which contains a replaceable rechargeable battery for powering a microprocessor and linear actuator contained within the housing. The lower portion of the housing comprises a vertically elongated handle which is

coaxial with the longitudinal axis of the housing. The handle has contiguous bilaterally symmetrical and vertically extending forward and rear portions for either right or left hand gripping by a user of the pipette. The forward portion of the handle extends forward of the upper portion of the housing and extends vertically downward to a lower end of the housing and in one embodiment internally contains and shields an upper portion of a pipette tip ejector. In the preferred embodiment of the design, the pipette tip ejector has a thumb actuated push button located at a top of the forward portion of the handle and a vertically moveable tip ejector arm extending below the housing and vertically along a pipette tip mounting shaft to encircle the shaft adjacent a lower end thereof. Thus configured, the pipette tip ejector is designed to eject a pipette tip from a lower end of the mounting shaft upon downward movement of the tip ejector arm. Such downward movement is in response to a downward thumb force exerted by the pipette user on the push button while the user is gripping the handle of the pipette. The rear portion of the handle extends rearward from the forward portion and has a hook extending rearward from a back of an upper end of the handle. The hook includes a downwardly curved lower surface for engaging an upper side of an index finger (or middle finger, if desired) of the user while the user is gripping the handle with the thumb of the user free to actuate any of the

bilaterally symmetrical control keys, trigger switches and push button in any sequence desired. All this the user is free to do while clearly viewing the alpha numeric display as it responds to the actuation of the control keys and trigger switches. In this regard, the hook, forward and rear portion of the handle and pipette tip ejector including push button and ejector arm are all bilaterally symmetrical relative to the longitudinal axis of the housing. Thus arranged, the pipette of the present invention is easily and comfortably gripped by the user in either his or her left or right hand with the user's index finger under the hook at the rear of the handle. This leaves the user's thumb free to actuate as desired any of the control keys or trigger switches which regulate the various modes of operation of the electronic pipette as well as the volumes of liquid aspirated and dispensed thereby during the several modes of operation of the pipette. All this is accomplished comfortably by the user while exerting minimal thumb forces on the control keys, trigger switches and push button. Thus, the electronic pipette of the present invention is useable by the user over extended periods of time without unduly stressing the user's thumb, hand or forearm enabling accurate and repeatable operation of the pipette in all operational modes of pipette under control of the user.

The electronic pipette of the present invention also

preferably incorporates a relatively simple electronic control circuit which enables the software controlled microprocessor to function as a microcontroller generating pulse width modulated (PWM) drive signals for the windings of a stepper motor included in the linear actuator. The PWM signals are generated in synchronism with clock pluses defining the stepping rate of the motor. This allows the PWM signals to be generated by the microcontroller without the control circuit requiring the use of conventional current sensing or feedback circuitry.

The electronic control circuit also minimizes the power requirements of the stepper motor thereby reducing power drain on the battery which powers the pipette. This, in turn, extends the operating life of the pipette between required recharging of the battery.

The electronic control circuit also compliments the user friendly control of the pipette enabling the user to easily switch between the various operating modes of the pipette and in each mode to select between a variety of operating speeds and operating features including cycle counting. When the cycle counting feature is selected by the pipette use, the user is continuously advised of the operational cycle of the pipette. This enables the user to interrupt a sequence of pipette operations without losing tract of the particular cycle of operation of the pipette.

Further, the electronic control circuit of the pipette of the present invention provides for a sequential recharging of a number of pipettes from a single source.

Brief Description of Drawings

Fig. 1 is a perspective view of a preferred embodiment of the electronic pipette of the present invention.

Fig. 2 is a cross sectional side view of the pipette of Fig. 1 showing the internal construction of the pipette and the component parts thereof.

Fig. 3 comprising Figs. 3A-3E combine to illustrated the electronic circuit of the pipette of the present invention.

Fig. 4 is timing diagram of the PWM drive signals applied to the gate of the field effect transistors ("FETs") driving the coils of the stepper motor of the preferred form of the electronic pipette of the present invention.

Fig. 4a is a timing diagram illustrating one pulse width modulation period of the motor drive signals to the control gates of two motor H-bridges in the drive circuitry for the motor.

Fig. 4b comprising Figs. 4b-1 and 4b-2 is a numeric table illustrating four different power ranges for the motor drive pulse width modulation signals as a function of the motor microstep position.

A summary of the key press actions in the Manual mode follows:

At the Home position:

"Arrows"	Adjust pickup volume or the cycle counter count, whichever is selected.
"Reset"	Normal duration press selects pickup volume or cycle counter count, if on, otherwise it does nothing. Long duration press zeros cycle counter, if on, otherwise it does nothing.
"Mode"	Normal duration press toggles to next mode. Long duration press activates (or deactivates) the Option menu display.

After a Pickup:

"Arrows"	Do nothing.
"Reset"	Normal duration press dispenses, blows out, pauses, and returns to home position Long duration press zeros volume display.
"Mode"	Does nothing.

Multiple Dispense Mode

The microprocessor 38 software flow diagram for the Multiple Dispense Mode of pipette operation is depicted in Figs. 16A and F16B. When toggling to this mode by activating

the Mode key, the dispense volume is active and can be edited with the arrow keys 28a, 28b. The dispense volume can be changed when the unit is at "Home" as well as while the unit is waiting to dispense. When the dispense volume is changed the number of aliquots is recalculated and displayed on the display 22 in the two small, dedicated digits adjacent to the "X" symbol. If the pipette is at "Home", the number of aliquots is calculated to be the largest it can be and still have a sufficiently large residual volume (i.e.; a full scale pickup). The residual volume can be easily changed since it is stored in the EEPROM memory U8. If the dispense volume value is changed while dispensing then the number of aliquots, "X", is recalculated to represent the remaining aliquots in the tip (assuming the dispense volume remains unchanged for the remaining aliquots.) The volume can be changed at any and all pause points while in the dispense phase (within the limits of the remaining volume left in the tip.) After each dispense volume is dispensed the number of aliquots decrements by one so that the display always shows how many aliquots are remaining in the tip. When "X" reaches zero the display flashes the "reset" symbol to remind the user to press the "reset" key.

If the user does not want to aspirate a full scale load in the tip then he can decrease the calculated number of aliquots while still at "Home" before pickup. To do this the

user presses the "Reset" key which activates the number of aliquots field for editing. The number of aliquots digits and the "X" symbol flash indicating that the arrow keys will change the number of aliquots. The number of aliquots field remains activated until either the "Reset" key is pressed again, or a trigger is pressed, in either case the dispense volume becomes activated (but, if the trigger was pushed liquid is also aspirated). While at the "Home" position pressing the "Reset" key alternately activates the dispense volume and the number-of-aliquots field. If the "X" value has been reduced from the default calculation then it remains unchanged until the user either changes it again or changes the dispense volume; changing the mode (or pressing reset) will not change the settings. Whenever the dispense volume in the Multiple Dispense Mode is changed then a new, full scale "X" value will be automatically calculated.

As depicted in Fig.16A, when the pipette has been preset by activation of the arrow and reset keys as described above and using the previously described Arrow Key and Reset Key routines, the user activates one of the trigger switches (30, 32). While the presettings are stored, the microprocessor 38 controls the motor 40 to pick up into the tip 60 a volume of liquid in excess of volume equal to the aliquot volume times the number of aliquots (selected total volume). The motor reverses to dispense some of the liquid leaving in the tip the

correct selected total volume and a residual volume of liquid. At that point, the arrow keys can be activated to modify the aliquot volume if so desired accompanied by any necessary microprocessor recalculation of the number of aliquots. Activation of the Reset key 26b will then cause the pipette to dispense all liquid in the tip overriding the multi-mode operation of the pipette.

In response to activation of one of the trigger switches, however, the pipette enters the microprocessor controlled dispense routine depicted in Fig. 16B with the microprocessor introducing offset corrections according to data stored in the EEPROM memory U8 such as correction data similar to the correction curve and tables of Figs. 9 and 9a-9f as described for the Pipet Mode of pipette operations. This operation is repeated for each subsequent activation of a trigger switch until all aliquots have been dispensed. At that point, either activation of the Reset Key or a double click of the trigger switch will cause the microprocessor to drive the motor into a blow out routine in which the plunger 90 is driven past "home" to blow all residual liquid from the tip and the plunger is returned to "home" and the presettings are restored readying the pipette for a second multiple dispense operation.

In the Multiple Dispense mode, the only option on the Option menu is the speed setting which operates in the manner previously described.

Therefore, to sum-up:

At the Home position:

"Arrows"	Adjust dispense volume or the aliquot number, whichever is selected.
"Reset"	Normal duration press selects dispense volume or the aliquot number. Long duration press does nothing.
"Mode"	Normal duration press toggles to next mode. Long duration press activates (or deactivates) the Option menu display allowing the speed setting to be adjusted.

After a Pickup:

"Arrows"	Adjust volume & remaining aliquots are recalculated.
"Reset"	Normal duration press dispenses, blows out, pauses, and returns to home position Long duration press does nothing.
"Mode"	Does nothing.

When last aliquot has been dispensed (and user is prompted to reset):

	"Arrows"	Perform reset as below:
"Reset"		Normal duration press dispenses, blows out, pauses, and returns to home position (volume setting and aliquot number are returned to the values last set by the arrows by the user in the home position in multi-dispense.)
	"Mode"	performs reset, as above, and then toggles to next mode

displayed to indicate the pipette is in any of the three low battery states. It does not flash as that would be potentially confusing given that the lightning bolt flashes when the pipette is charging.

Battery Power Management and Recharge Circuitry 106

The battery 36 included with the pipette 10 is a lithium-ion battery having a 400 ma-hour rating. Thus, the average charging current to the battery should be limited to a maximum of 400 ma (i.e.; a 1C rate) to avoid potential damage to the battery. The motor 40 draws a maximum current of more than 800 ma during operation. Since it is desired that the pipette 10 be able to operate from a wall power supply 37

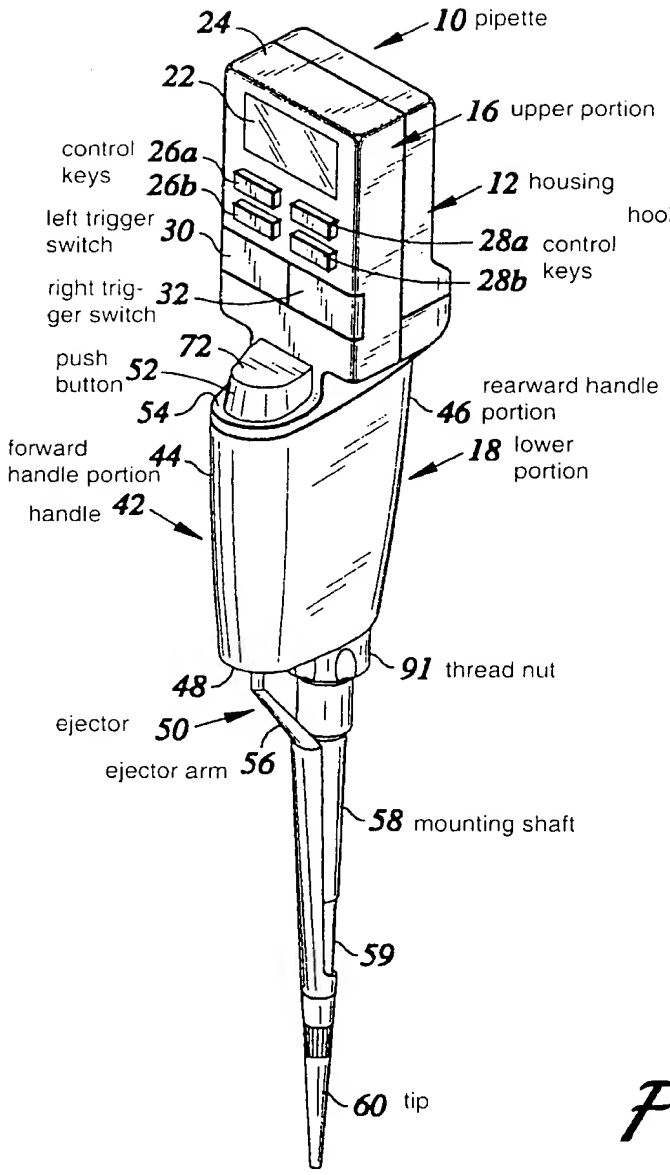

24
10 pipette
22
16 upper portion
control keys 26a
26b
12 housing
left trigger switch 30
28a control keys
28b
right trig- ger switch 32
push button 52
72
54
rearward handle portion 46
forward handle portion 44
18 lower portion
handle 42
91 thread nut
48
ejector 50
ejector arm 56
58 mounting shaft
59
60 tip

Fig. 1

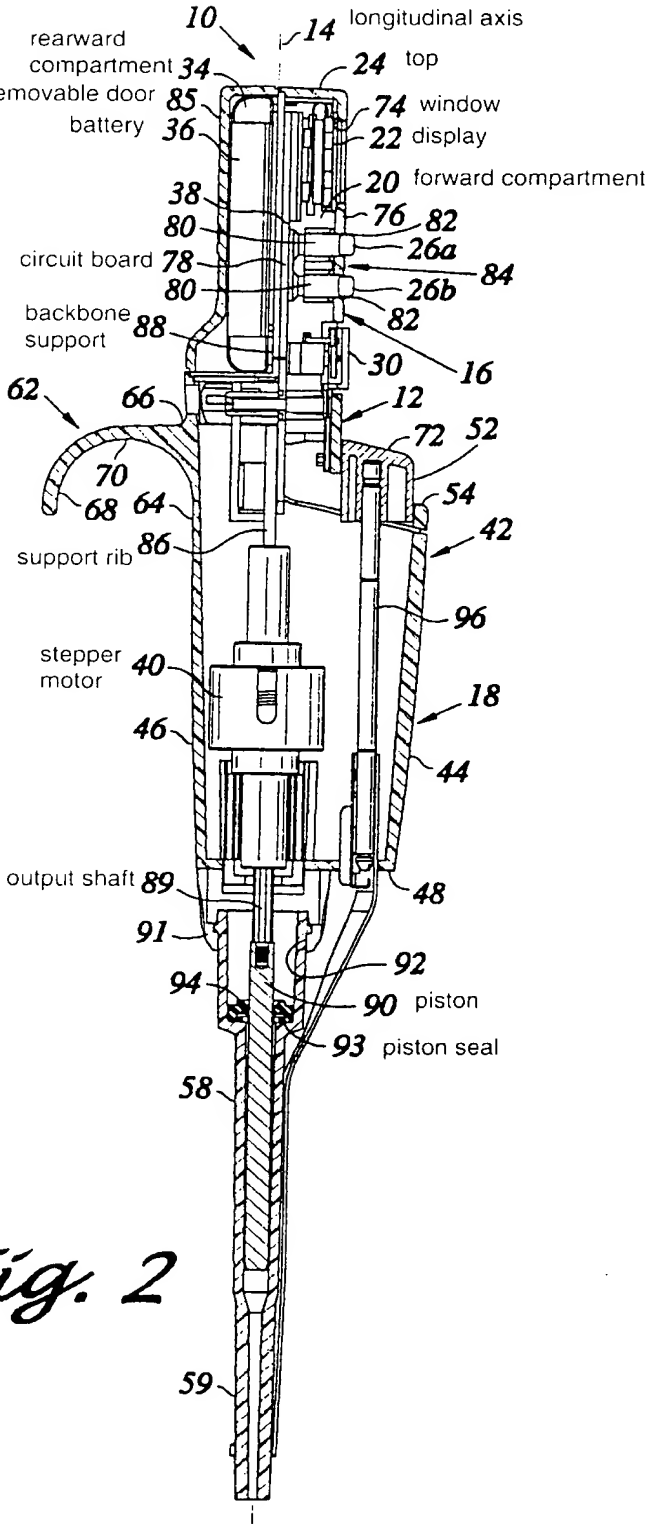

10
14 longitudinal axis
rearward compartment 34
24 top
removable door 85
74 window
battery 36
22 display
20 forward compartment
38
76 82
80
26a
circuit board 78
84
80
26b
backbone support 88
82
30
16
hook 62
66
12
72 52
70
68 64
54
support rib 86
42
96
stepper motor 40
18
46
44
output shaft 89
48
91
92
94
90 piston
93 piston seal
58
59

Fig. 2

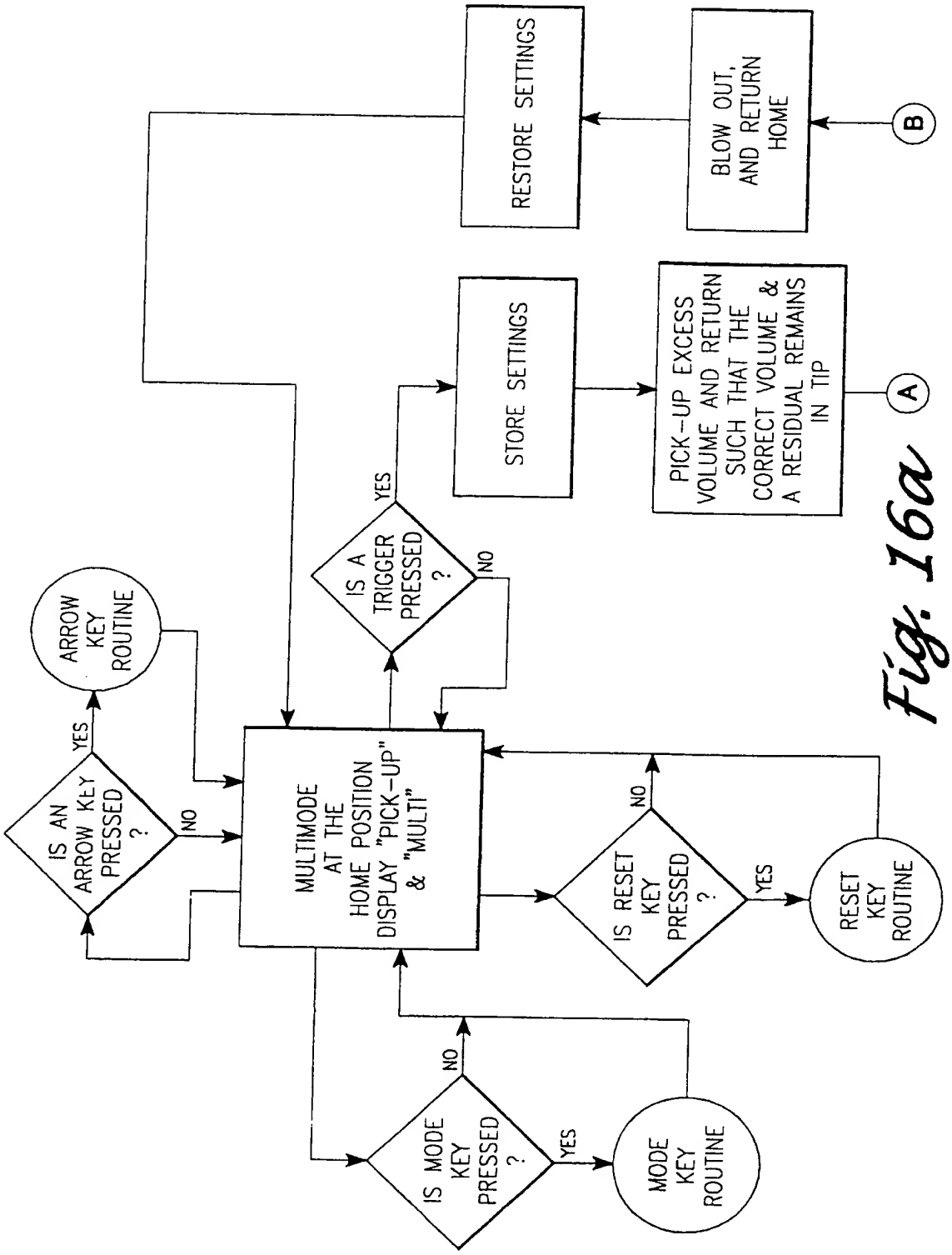

RESTORE SETTINGS
BLOW OUT, AND RETURN HOME
B
STORE SETTINGS
PICK-UP EXCESS VOLUME AND RETURN SUCH THAT THE CORRECT VOLUME & A RESIDUAL REMAINS IN TIP
A
YES
IS A TRIGGER PRESSED ?
NO
ARROW KEY ROUTINE
YES
IS AN ARROW KEY PRESSED ?
NO
MULTIMODE AT THE HOME POSITION DISPLAY "PICK-UP" & "MULTI"
NO
IS RESET KEY PRESSED ?
YES
RESET KEY ROUTINE
NO
IS MODE KEY PRESSED ?
YES
MODE KEY ROUTINE

Fig. 16a

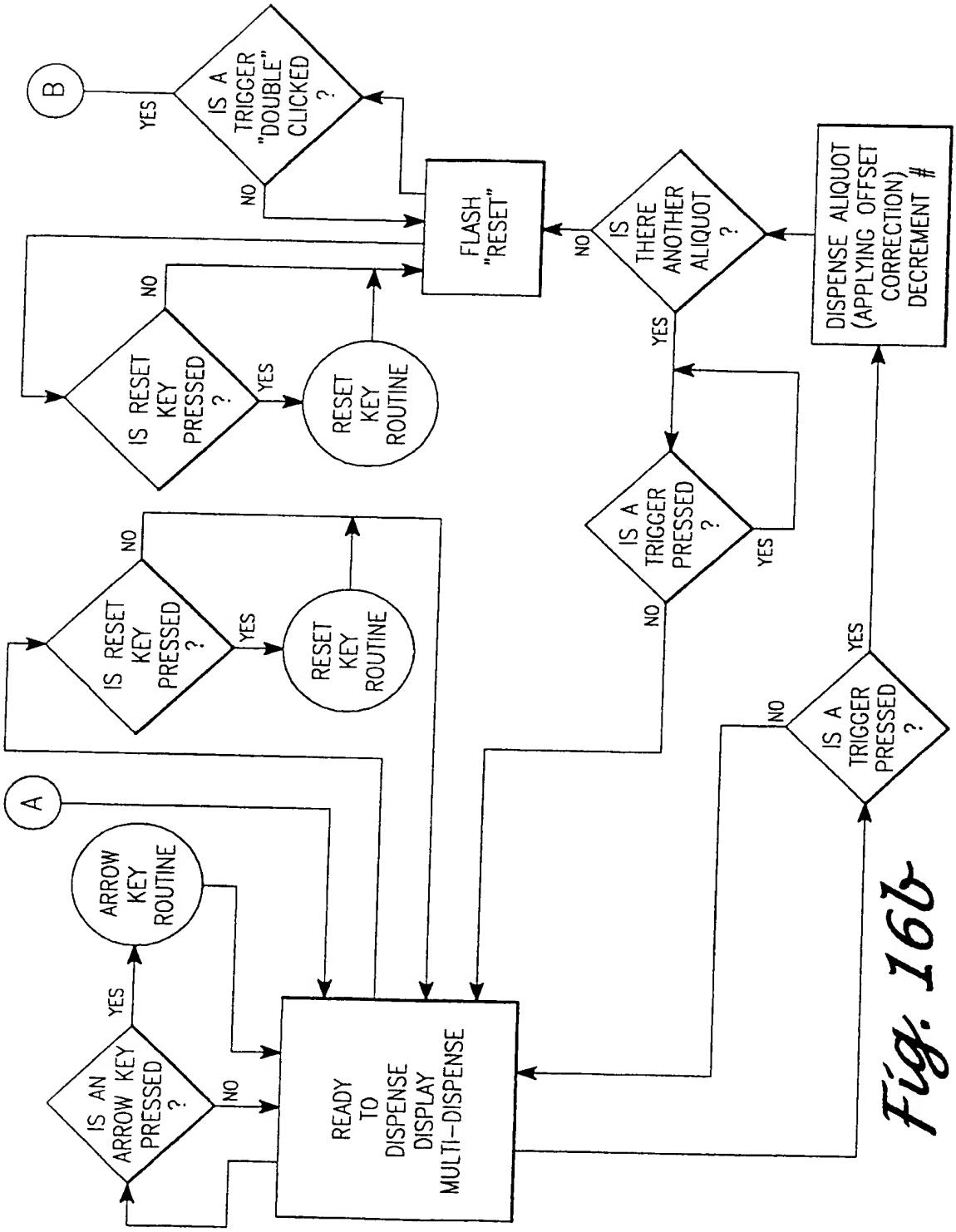

READY TO DISPENSE DISPLAY MULTI-DISPENSE
IS AN ARROW KEY PRESSED ?
YES
NO
ARROW KEY ROUTINE
A
IS RESET KEY PRESSED ?
YES
NO
RESET KEY ROUTINE
IS RESET KEY PRESSED ?
YES
NO
RESET KEY ROUTINE
IS A TRIGGER PRESSED ?
YES
NO
IS THERE ANOTHER ALIQUOT ?
YES
NO
DISPENSE ALIQUOT (APPLYING OFFSET CORRECTION) DECREMENT #
IS A TRIGGER PRESSED ?
YES
NO
FLASH "RESET"
IS A TRIGGER "DOUBLE" CLICKED ?
YES
NO
B

Fig. 16b

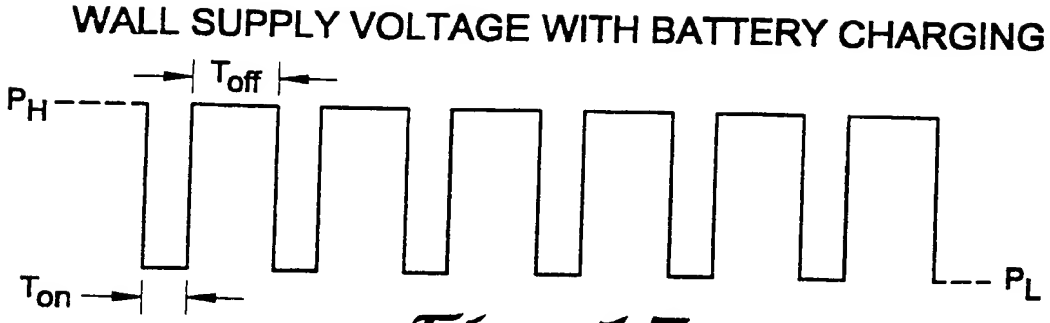

WALL SUPPLY VOLTAGE WITH BATTERY CHARGING
Toff
PH
Ton
PL

Fig. 17

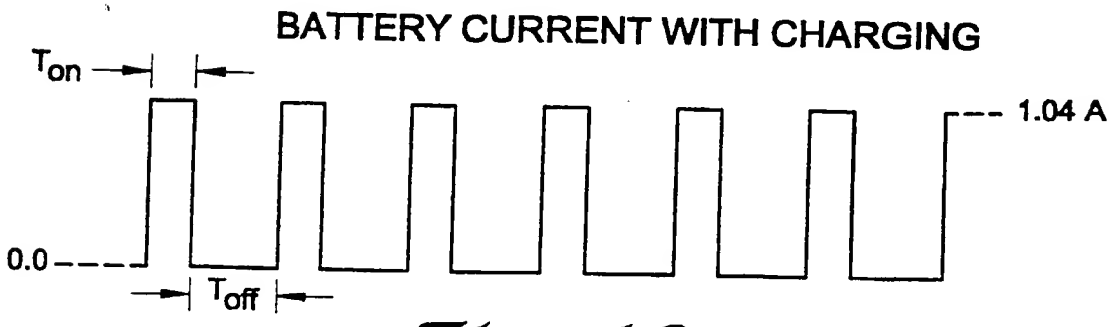

BATTERY CURRENT WITH CHARGING
Ton
1.04 A
0.0
Toff

Fig. 18

BATTERY CHARGING LEVELS

CHARGING LEVEL	Ton (ms)	Toff (ms)	PERIOD (ms)	DUTY CYCLE (%)	CURRENT (ma)	C RATE	VT (n)
PRE-CHARGE	0.36	9.64	10	3.6	37	0.09	3
0	0.36	0.64	1	36.0	374	0.94	3.95
1	0.36	1.4	1.76	20.5	213	0.53	4.025
2	0.36	2.64	3	12.0	125	0.31	4.075
3	0.36	5.64	6	6.0	62	0.16	4.1
4	0.36	11.64	12	3.0	31	0.08	4.1
5	0.36	23.64	24	1.5	18	0.04	4.1

Fig. 19

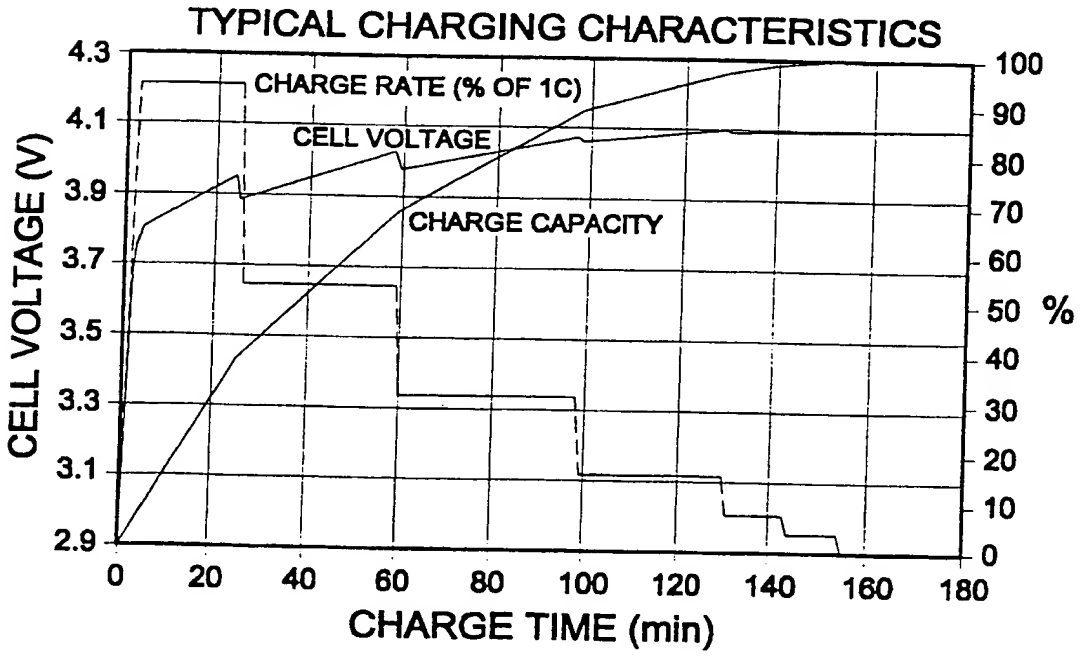

TYPICAL CHARGING CHARACTERISTICS
CHARGE RATE (% OF 1C)
CELL VOLTAGE
CHARGE CAPACITY
CELL VOLTAGE (V)
4.3
4.1
3.9
3.7
3.5
3.3
3.1
2.9
100
90
80
70
60
50
40
30
20
10
0
%
0
20
40
60
80
100
120
140
160
180
CHARGE TIME (min)

Fig. 20

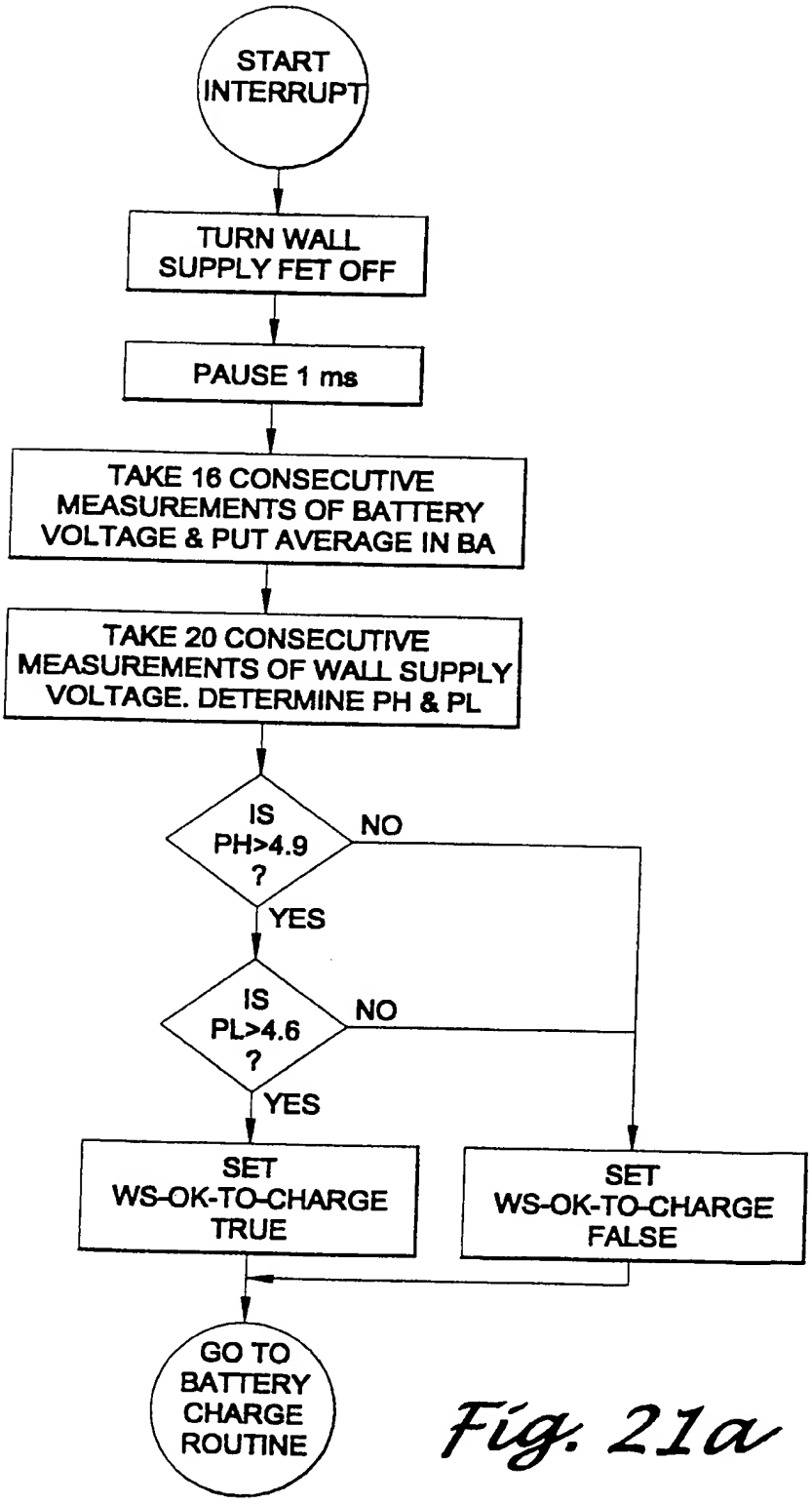

START INTERRUPT
TURN WALL SUPPLY FET OFF
PAUSE 1 ms
TAKE 16 CONSECUTIVE MEASUREMENTS OF BATTERY VOLTAGE & PUT AVERAGE IN BA
TAKE 20 CONSECUTIVE MEASUREMENTS OF WALL SUPPLY VOLTAGE. DETERMINE PH & PL
IS PH>4.9 ?
NO
YES
IS PL>4.6 ?
NO
YES
SET WS-OK-TO-CHARGE TRUE
SET WS-OK-TO-CHARGE FALSE
GO TO BATTERY CHARGE ROUTINE

Fig. 21a

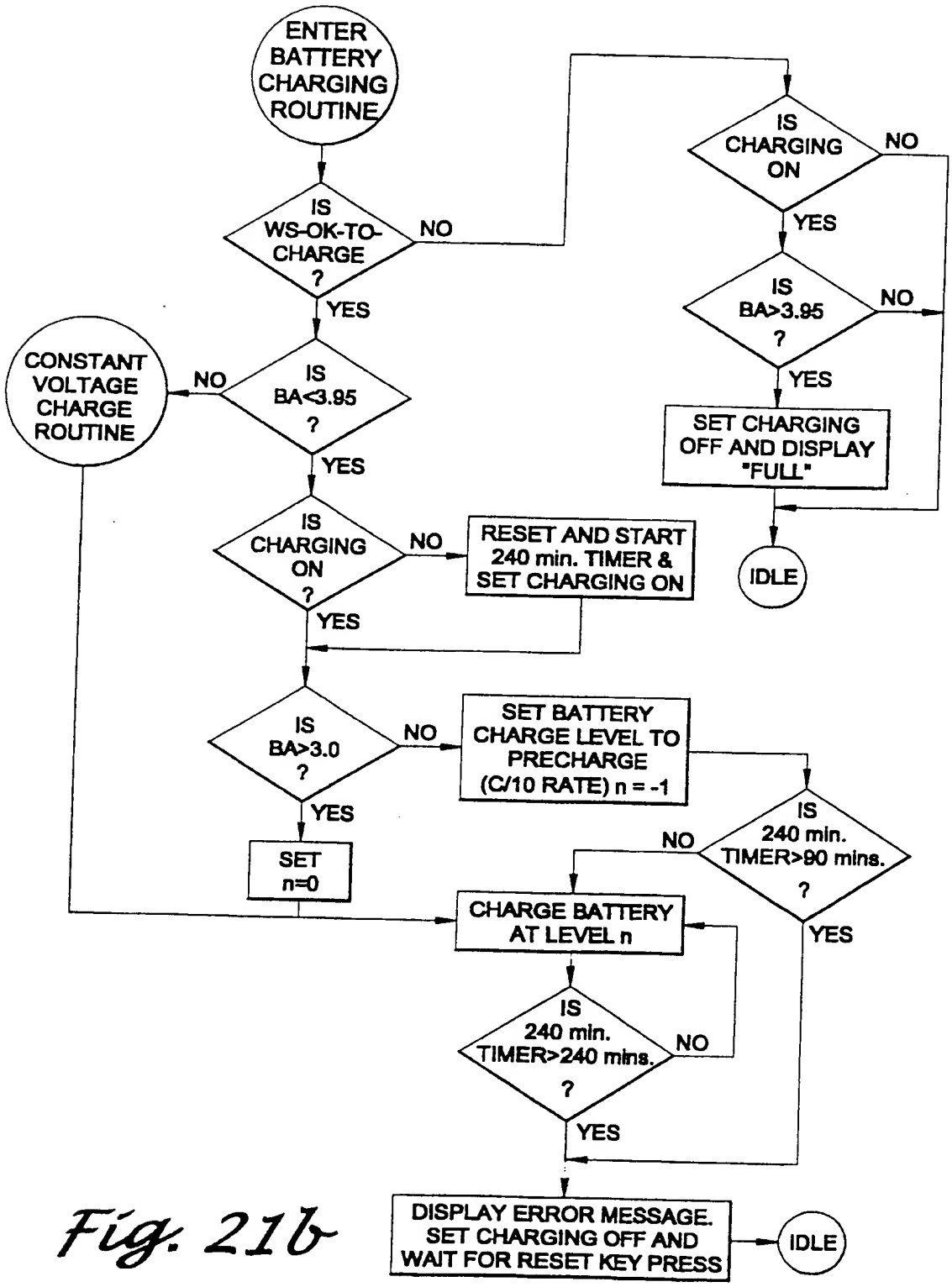
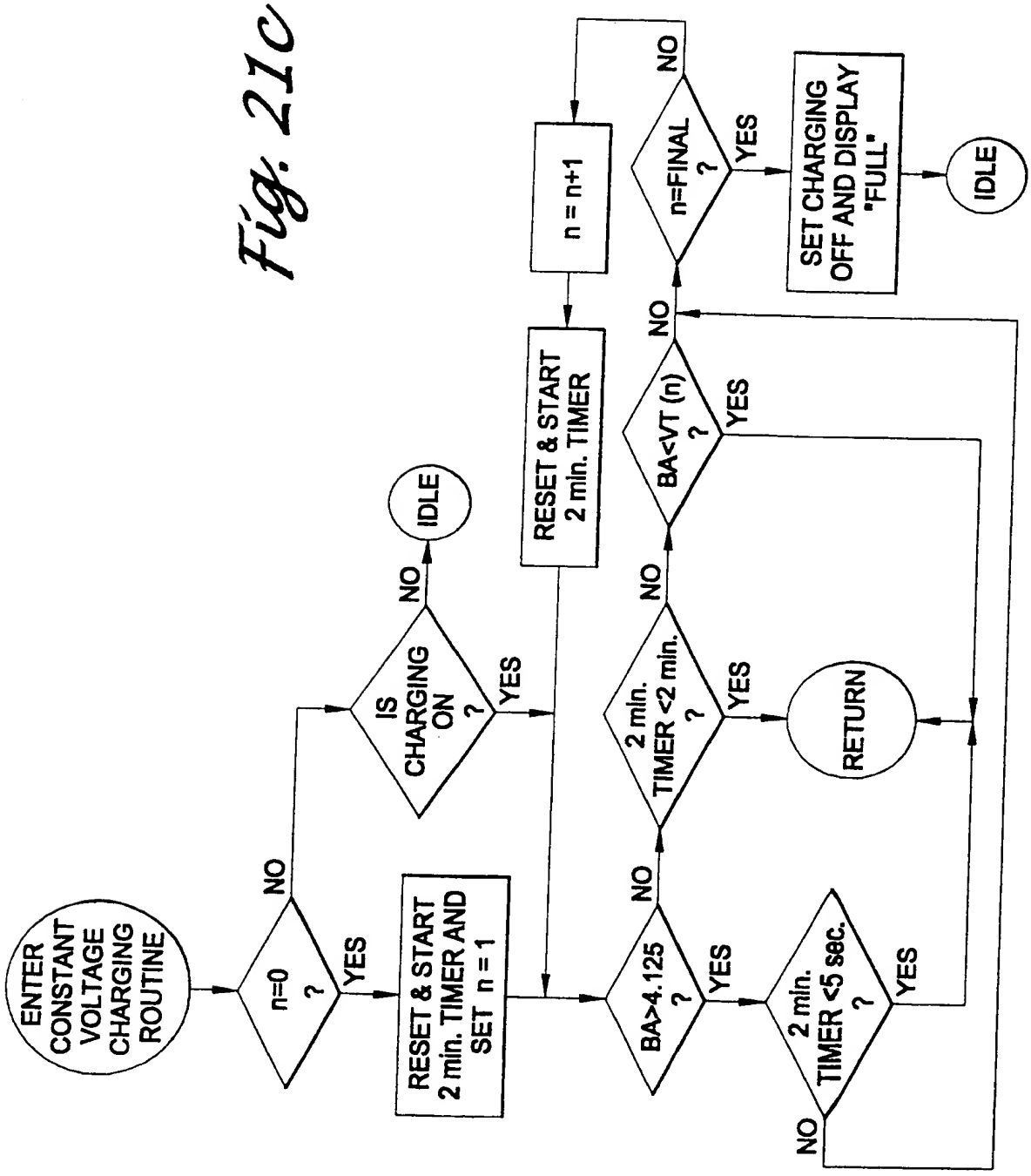

ENTER BATTERY CHARGING ROUTINE
IS WS-OK-TO-CHARGE ?
NO
YES
IS CHARGING ON
NO
YES
IS BA>3.95 ?
NO
YES
SET CHARGING OFF AND DISPLAY "FULL"
IDLE
CONSTANT VOLTAGE CHARGE ROUTINE
NO
IS BA<3.95 ?
YES
IS CHARGING ON ?
NO
RESET AND START 240 min. TIMER & SET CHARGING ON
YES
IS BA>3.0 ?
NO
SET BATTERY CHARGE LEVEL TO PRECHARGE (C/10 RATE) n = -1
YES
SET n=0
IS 240 min. TIMER>90 mins. ?
NO
YES
CHARGE BATTERY AT LEVEL n
IS 240 min. TIMER>240 mins. ?
NO
YES
DISPLAY ERROR MESSAGE. SET CHARGING OFF AND WAIT FOR RESET KEY PRESS
IDLE

Fig. 21b

Fig. 21c


ENTER CONSTANT VOLTAGE CHARGING ROUTINE
n=0 ?
YES
NO
RESET & START 2 min. TIMER AND SET n = 1
IS CHARGING ON ?
YES
NO
IDLE
RESET & START 2 min. TIMER
n = n+1
BA>4.125 ?
YES
NO
2 min. TIMER <5 sec. ?
YES
NO
2 min. TIMER <2 min. ?
YES
NO
RETURN
BA<VT (n) ?
YES
NO
n=FINAL ?
YES
NO
SET CHARGING OFF AND DISPLAY "FULL"
IDLE

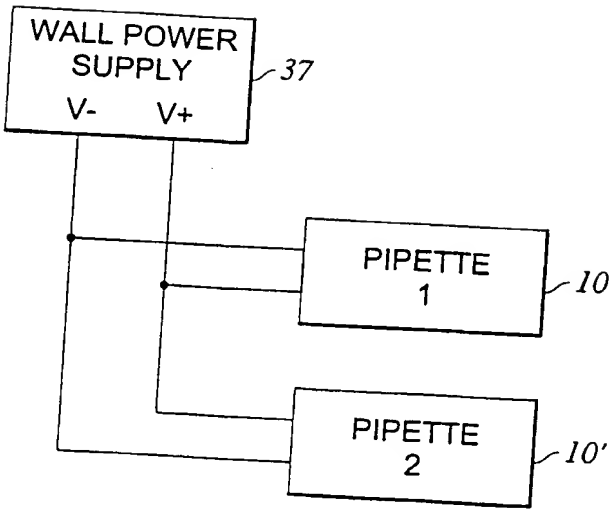


Fig. 22